Toward Realistic Modeling of a Shelfbreak Front: Lagrangian Metrics and Process Studies for the Middle Atlantic Bight

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LONG-TERM GOALS

A region where predictive capability is sought for tactical concerns is the flow field in the vicinity of the continental shelfbreak. Sound propagation from the continental slope to the continental shelf is a complex process that is highly dependent upon the oceanographic environment. A strong thermal shelfbreak front, and its associated current, are the key features that influence acoustic propagation in many shelf regions. Theory and field data suggest that acoustic propagation is strongly affected by frontal features that can evolve on rapid temporal scales (1-2 days) and small spatial scales (10-20 km). The overall aim of this proposed work is to improve our ability to realistically model and predict the evolution of the shelfbreak front so as to advance the predictive capability of this region.

OBJECTIVES

This work focuses specifically on ascertaining the dominant mechanisms for the frontal variability in the Middle Atlantic Bight, on establishing Lagrangian metrics to judge how well three-dimensional deterministic models reproduce these mechanisms, and on establishing the degree of predictability of the ocean in the vicinity of the shelfbreak front. While this work is specifically focused on the environmental conditions of the Middle Atlantic Bight, its applicability extends to other geographic locales where relatively robust shelfbreak frontal jets exist, such as in the South China Sea, the Black Sea and in some shelf regions of the Antarctic.

APPROACH

To address the objectives of this work, three projects are being pursued. The first project involves the study of the stability of the shelfbreak frontal current. A dynamic model developed by Moore and Peltier (1987), and modified by Xue and Mellor (1993) to include bathymetry, is employed. The model uses linearized primitive equation dynamics to determine the growth of three-dimensional perturbations along a two-dimensional background front. As discussed by Xue and Mellor (1993) and Moore and Peltier (1987) the use of primitive equations successfully captures the cyclonic-scale modes. These modes are filtered out with the geostrophic momentum approximation, which is commonly used in shelf dynamics. For each model configuration, wavenumber space is explored to establish the stability/instability of each selected flow field. From the unstable waves the dominant wave is identified and the evolution of the front is characterized with a wavelength, phase speed, growth rate and modal structure. Model configurations include changes in the horizontal and vertical

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14. ABSTRACT
A region where predictive capability is sought for tactical concerns is the flow field in the vicinity of the continental shelfbreak. Sound propagation from the continental slope to the continental shelf is a complex process that is highly dependent upon the oceanographic environment. A strong thermal shelfbreak front, and its associated current, are the key features that influence acoustic propagation in many shelf regions. Theory and field data suggest that acoustic propagation is strongly affected by frontal features that can evolve on rapid temporal scales (1-2 days) and small spatial scales (10-20 km). The overall aim of this proposed work is to improve our ability to realistically model and predict the evolution of the shelfbreak front so as to advance the predictive capability of this region.

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structure of the velocity and density fields. Dr. Mark Reed, a computational scientist at the North Carolina Supercomputing Center, works on the development and implementation of this modeling project.

A second project involves an evaluation of the predictability of the shelfbreak front in the Middle Atlantic Bight using nonlinear time series analysis. The use of nonlinear techniques will allow for the determination of whether the system behaves principally as a stochastic or deterministic system, a determination that has direct bearing on our attempts to model, and analyze, this ocean flow field. Nonlinear time series analysis is being applied to historical current meter data from the Nantucket Shoals Flux Experiment. Briefly, the essential goal of this analysis is to build a deterministic model by using time-delay vectors obtained from the time series. To first assess whether a nonlinear analysis is appropriate for this data, we have created surrogate time series from the original time series. A comparison of the nonlinear prediction errors generated by the surrogate time series to those of the original time series lends insight into whether a deterministic or stochastic model is more appropriate for the prediction of the flow field and its properties. Dr. Guocheng Yuan, a research associate in the Department of Applied Mathematics at Brown University, is performing the computations for this project. Dr. Larry Pratt (Woods Hole Oceanographic Institution) and Dr. Christopher Jones (Brown University) are collaborators on this project.

A third project is focused on the determination of how well models capture the observed processes of a shelfbreak frontal region, and the observed variability. This observational study involves the analysis of a set of surface drifters that were present in the Middle Atlantic Bight from 1995 to 1997.

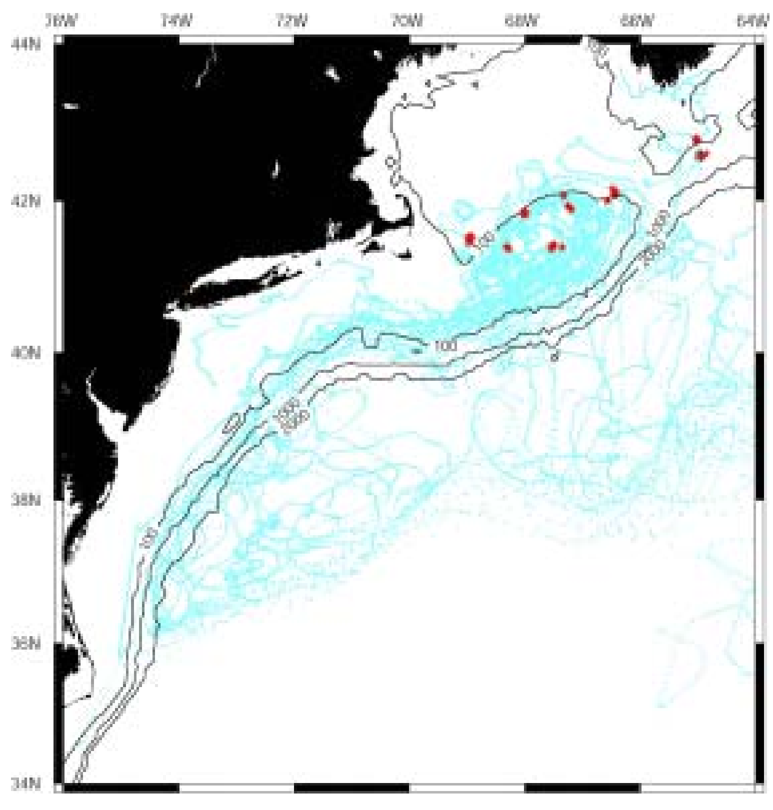

Figure 1: Surface Drifters in the Middle Atlantic Bight
[plot: Lagrangian pathways showing continuity and variability of the shelfbreak current]

These drifters, launched over Georges Bank as part of a GLOBEC Northwest Atlantic program were entrained into the shelfbreak jet from the onshore side of the front and then generally advected downstream to the southwest, collectively demonstrating the continuity of the frontal jet from Georges Bank to Cape Hatteras (Lozier and Gawarkiewicz, 2001). The specific purpose of this work is to develop Lagrangian metrics for the evaluation of fully 3-d models of the coastal ocean. Meander wavelength and phase speed are to be calculated and then compared to the dominant scales of variability in the 3-d models. The nature of the mismatch (if there is one) between the observed and modeled scales will lend insight toward model improvement. Another important use of the drifter data is to calculate Lagrangian integral time scales. This measure can be calculated for the velocity time series for the drifters and for the temperature time series. This quantity will be measured for all drifters and differences in season and offshore/onshore placement will be determined. A measure of the Lagrangian integral time scale will also give an indication of whether the whole idea of chaotic advection is relevant to the Middle Atlantic Bight. In addition to Lagrangian integral time scales, autocorrelations will be computed, as well as statistics on path history. In conjunction with Dale Haidvogel (Rutgers), I plan to compare these Lagrangian metrics to analogous modeled quantities.

WORK COMPLETED

During the past year a parameter study on the stability of the shelfbreak frontal current in the Middle Atlantic Bight has been completed. The results of this comparison are contained in a paper, Instability of a shelfbreak front, which is currently in press in the *Journal of Physical Oceanography.*

During the past year techniques for creating surrogate data time series from observed time series have been developed and successfully employed. Additionally, linear and nonlinear prediction models for current meter data from the Nantucket Shoals Flux Experiment have been developed. This work will be presented at the Fall 2001 AGU meeting in San Francisco.

RESULTS

A stability analysis of a two-dimensional geostrophic jet overlying shelfbreak topography has found the jet to be unstable to perturbations for a wide range of background conditions. While earlier studies of shelfbreak frontal instabilities found growth rates to be prohibitively small to be of consequence in the energetic shelfbreak region, the model growth rates from this study are on the order of one day. Such rapid growth would clearly lead to substantial temporal and spatial variability for the shelfbreak front. The inclusion of continuous horizontal and vertical shear for the background density and velocity field, as well as the use of primitive equation dynamics, are believed to be responsible for the capture of physical modes with rapid growth rates. While the perturbations with the shortest wavelengths generally had higher growth rates, often the growth rate curves were relatively flat at high wavenumbers, suggesting a range of wavelengths might be present in the shelfbreak vicinity, rather than one dominant wavelength. Indeed, past observations of spatial variability in the Middle Atlantic Bight have not narrowly defined the dominant spatial scale of the eddy motions. Collectively, these past studies have reported a range of from 10 to 75 km for the spatial scale, a range that is consistent with our model results.

Because the shelfbreak frontal jet in the Middle Atlantic Bight exhibits a large degree of variability about its climatological mean winter and summer states, an envelope of possible synoptic jet structures were tested in a parameter study. Jet width, depth and velocity maximum were varied, along with stratification, in an attempt to isolate the relative importance of the Rossby number, the vertical

velocity shear, the maximum velocity and the Burger number to the stability of the background jet. Changes to the background fields were based on the range of conditions present in the Middle Atlantic Bight. Overall, growth rates increased as the jet's maximum velocity increased, as the Rossby number increased and as the jet's velocity shear in the vertical increased. A decrease in growth rate resulted from an increase in the jet's stratification. Thus, a fast, narrow, shallow jet with relatively weak stratification maximizes the growth rate of the unstable perturbations. Of all the parameters tested, the model growth rates were the least sensitive to changes in the background stratification. This result runs somewhat counter to the notion that a summer jet is more stable than a winter jet because of the strong stratification provided by seasonal heating. All things being constant, these model results do show this to be true, but if the summer jet also happens to be faster or narrower or shallower than the winter jet, it is likely to be more unstable. Thus, seasonal differences in stability may not be controlled solely by seasonal changes in stratification if the seasons also bring significant changes in the width and depth and strength of the jet. Considering the strong sensitivity of the stability characteristics to the structure of the velocity field, it is likely that changes in the stability of the frontal jet on the order of days may occur if the background jet is altered due to ring interactions, slope water variability, riverine input, and/or local wind events. It seems likely that the stability may change more rapidly on synoptic time scales than on seasonal time scales.

From our preliminary investigation of the Nantucket Shoals Flux Experiment, it appears that the time series contain both deterministic and stochastic components. However, the stochastic component is more vigorous near the slope than on the shelf. Even for moorings on the shelf, the time series are so complicated that they cannot be simply modeled by a low-dimensional deterministic model. A comparison of nonlinear prediction errors with linear prediction errors for temperature, along-shelf and cross-shelf velocity show that deterministic models are superior to linear models. This analysis has demonstrated that even when the model is run such as to produce a chaotic time series, a deterministic model can yield excellent short-term prediction.

IMPACT/APPLICATIONS

The collective impact of this work is/will be on the prediction of the physical environment through which sound propagates.

TRANSITIONS

The instabilty model used in this study and the associated expertise have been transferred to Dr. Glen Gawarkiewicz and Mr. Chris Linder, both of the Woods Hole Oceanographic Institution. Dr. Gawarkiewicz and Mr. Linder plan to use the model to test seasonal differences in the Middle Atlantic Bight and base the background fields on observed fields from the ONR PRIMER program.

The nonlinear time series analysis has also been applied to data collected in the South Atlantic Bight by Dr. Harvey Seim of the University of North Carolina. Dr. Seim will visit Duke in October of 2001 to learn more about the nonlinear time series analysis developed under this contract.

RELATED PROJECTS

Dr. Glen Gawarkiewicz’s work on both the modeling of the Middle Atlantic Bight and the analysis of observational data are strongly related to the work from this grant.

Dr. Dale Haidvogel's efforts to model the Middle Atlantic Bight are related to the work under this contract. The development of Lagrangian metrics from the drifter data will be compared to Lagrangian data from the numerical model which Dr. Haidvogel is developing.

REFERENCES

Lozier, M. S. and G. G. Gawarkiewicz, 2001. Cross-frontal exchange in the Middle Atlantic Bight as evidenced by surface drifters. *Journal of Physical Oceanography,* **31**, 2498 - 2510.

Lozier, M. S., M. S. Reed and G. G. Gawarkiewicz, 2001. Instability of a shelfbreak front. *Journal of Physical Oceanography* (in press).

Moore, G. W. K. and W. R. Peltier, 1987. Cyclogenesis in frontal zones. *J. Atmos. Sci*., **44**, 384-409.

Xue, H. and G. Mellor, 1993. Instability of the Gulf Stream Front in the South Atlantic Bight. *J. Phys. Oceanogr*., **23**, 2326-2350.

PUBLICATIONS

Lozier, M. S. and G. G. Gawarkiewicz, 2001. Cross-frontal exchange in the Middle Atlantic Bight as evidenced by surface drifters. *Journal of Physical Oceanography*, **31**, 2498 - 2510.

Lozier, M. S., M. S. Reed and G. G. Gawarkiewicz, 2001. Instability of a shelfbreak front. *Journal of Physical Oceanography* (in press).